Encapsulation of Electronic Devices

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~~This application claims the priority of patent application titled "Encapsulation of Organic LED Devices", PCT Application Number: PCT/SG99/00143 (attorney docket number 99E02809SG).~~

Field of the Invention

The present invention relates to organic LED (OLED) devices. More particularly, the invention relates to packaging of OLED devices.

Background of the Invention

Fig. 1 shows an OLED device 100. The OLED device comprises one or more organic functional layers 110 between first and second electrodes 105 and 115. The electrodes can be patterned to form, for example, a plurality of OLED cells to create a pixilated OLED device. Bond pads 150, which are coupled to the first and second electrodes, are provided to enable electrical connections to the OLED cells.

To protect the OLED cells from the environment such as moisture and/or air, a cap 160 encapsulates the device. The active and electrode materials of the OLED

cells are sensitive and can be easily damaged due to mechanical contact with, for example, the cap. To prevent damage to the OLED cells, a cavity cap or package is used. The cavity package provides a cavity 145 between the cap and OLED cells. The cavity also allows for the placement of desiccant materials to cope with finite leakage rate of the device.

Typically, the lateral dimensions of OLED devices are usually in the range of a few centimeters or more, depending on the applications. To accommodate the large lateral dimensions, thicker caps are used to provide the necessary mechanical stability to maintain the integrity of the cavity.

However, the demand for thin and flexible devices requires the use of thinner components, such as the cap and the substrate. Decreasing the thickness of the cap reduces its mechanical stability, making it more prone to bending which can cause the cavity to collapse, thereby damaging the OLED cells.

As evidenced from the above discussion, it is desirable to provide an OLED device having improved packaging, particularly those formed on thin or flexible substrates.

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Summary of the Invention

The invention relates to encapsulation for devices such as OLED devices. One or more OLED cells are provided in the device region of the substrate. A cap is mounted on the substrate to encapsulate the device. The cap forms a cavity in the device region, separating it from the OLED cells.

In accordance with the invention, spacer particles are provided in the device region to prevent the cap from contacting the OLED cells. In one embodiment, the spacer particles are randomly deposited on the substrate by spraying techniques. In one embodiment, the spacer particles are deposited by a dry spray technique. Alternatively, a wet spray technique is employed to deposit the spacer particles on the substrate. In one embodiment, the spacer particles are coated with an adhesive that can be cured after deposition of the spacer particles. Spacer particles in the non-device region are removed, leaving the spacer particles randomly distributed in the device region. A cap is mounted on the substrate to encapsulate the device. The spacer particles in the device region prevent the cap from contacting the OLED cells.

Brief Description of the Drawings

Fig. 1 shows an OLED device; and

Figs. 2-6 show a process for forming an OLED device in accordance with one embodiment of the invention.

Preferred Embodiments of the Invention

The invention relates generally to OLED devices. In particular, the invention provides a cost-effective package for encapsulating OLED devices, particularly those formed on flexible or thin substrates. In accordance with one embodiment of the invention, spacer particles are provided between the OLED cells and the cap. The spacer particles prevent the cap from contacting the OLED cells.

Figs. 2-6 show a process for fabricating an OLED device in accordance with one embodiment of the invention. Referring to Fig. 2, a substrate 201 is provided on which OLED cell or cells are formed. The substrate can comprise various types of materials, such as glass or polymer. Other materials which can adequately support the OLED cells are also useful.

In one embodiment, the substrate comprises a flexible material, such as a plastic film for forming a flexible device. Various commercially available plastic

films can be used to serve as the substrate. Such films, for example, include transparent poly(ethylene terephthalate) (PET), poly(butylene terephthalate) (PBT), poly(enthylene naphthalate) (PEN), polycarbonate (PC), polyamides (PI), polysulfones (PSO), and poly(*p*-phenylene ether sulfone) (PES). Other materials such as polyethylene (PE), polypropylene (PP), poly(vinyl chloride) (PVC), polystyrene (PS) and poly(methyl methyleacrylate) (PMMA), can also be used to form the substrate. A flexible substrate comprising thin glass or other flexible materials is also useful.

In one embodiment, the substrate is about 20 - 300 um thick. In some cases, the thin substrate may be mechanically unstable, creating processing problems. A temporary support layer (not shown) can be employed to stabilize the substrate during the fabrication process. The temporary support layer, for example, can be provided on the backside of the substrate. In one embodiment, the temporary support layer comprises a polymer foil coated with an adhesive for attaching to the substrate. After processing, the temporary layer is removed since the device package can be used to mechanically stabilize the device.

A conductive layer 205 is deposited on the substrate. The substrate can be provided with a barrier layer, such as silicon dioxide (SiO_2), beneath the conductive layer on the substrate surface prior to depositing the conductive. Barrier layers are particularly useful for substrates comprising soda lime glass. The barrier layer, for example, is about 20 nm thick. In one embodiment, the conductive layer comprises a transparent conductive material, such as indium-tin-oxide (ITO). Other types of transparent conductive layers, including zinc-oxide and indium-zinc-oxide, are also useful. Various techniques, such as chemical vapor deposition (CVD) physical vapor deposition (PVD), and plasma enhanced CVD (PECVD), can be employed to form the device layer. The conductive layer should be thin to reduce optical absorption and negative impact on subsequent film formation while satisfying electrical requirements. The conductive layer is typically about 0.02 - 1 μm thick.

Referring to Fig 3, the conductive layer 205 is patterned as desired to selectively remove portions of the layer, exposing portions 356 of the substrate. The patterned conductive layer serves as first electrodes for the OLED cells. In one embodiment, the conductive

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layer is patterned to form strips that serve as, for example, anodes of a pixelated OLED device. The patterning process can also form connections for bond pads. Conventional techniques, such as photolithography and etching, can be used to pattern the conductive layer. Patterning techniques using a stamp are also useful. Such techniques are described in co-pending international patent application titled "Mechanical Patterning of a Device Layer", PCT Application No. PCT/SG99/00074 (attorney docket number 99E 8062), which is herein incorporated by reference for all purposes.

One or more organic functional layers 310 are formed on the substrate, covering the exposed substrate portions and conductive layer. The functional organic layers comprise, for example, conjugated polymer or low molecular materials such as Alq_3. Other types of functional organic layers are also useful. The organic functional layers can be formed by conventional techniques, for example, wet processes such as spin coating or vacuum sublimation (for Alq3 organic layers). The thickness of the organic layers is typically about 2 – 200 nm.

Referring to Fig. 4, portions of the organic layers can be selectively removed to expose underlying layers

in regions 470 for bond pad connections. Selective removal of the organic layers can be achieved using, for example, a polishing process. Other techniques, such as etching, scratching, or laser ablation, are also useful.

In accordance with one embodiment of the invention, spacer particles 480 are deposited on the substrate. In one embodiment, the spacer particles comprise a spherical shape. Spacer particles having other geometric shapes, such as cubical, prism, pyramidal, or other regular or irregular shapes are also useful. The average mean diameter of the spacer particles is sufficient to maintain the desired height of the cavity, which for example is about 2 - 50 μm. The size and shape distribution of the spacer particles should be sufficiently narrow to ensure proper separation between the cap and OLED cells.

The spacer particles are preferably fixed to one side of the substrate to avoid any movement. In one embodiment, the spacer particles are coated with a thin layer of adhesive before deposition. The adhesive layer comprises, for example, epoxy resin or acrylic resin. In one embodiment, the adhesive is cured by heat treatment. In another embodiment, the adhesive is cured

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by exposure to ultraviolet radiation. In yet another embodiment, the adhesive comprises a hot melt material.

In one embodiment, the spacer particles are randomly distributed on the substrate. The spacer particles occupy both active and non-active parts (i.e., emitting and non-emitting areas) of the device. In another embodiment, the spacer particles are confined to the non-active areas. Various techniques such as photolithography technology can be employed to pattern the coverage of the spacer particles. Alternatively, shadow mask or stencil mask technology can be used. A shadow mask with the required pattern is placed in close proximity or direct contact with the surface before deposition of the spacer particles. During the spray application process, only the regions which are exposed by the mask will be covered with spacer particles. Alternatively, a patterned dry resist film can be laminated on the bare surface. After the spacer particles are deposited, the dry resist film is cured and removed from the surface, leaving the exposed areas covered with spacer particles. A liquid resist material can also be used in a similar manner.

The distribution or density of the spacer particles should be sufficient to prevent the cap from contacting

the OLED cells in the presence of mechanical stress, whether by designed (flexible devices) or accident (handling of the devices). The distribution can be varied to accommodate design requirements, such as the thickness of the cap, thickness of the substrate, and amount of device flexibility needed.

In a preferred embodiment, the spacer distribution is sufficient to maintain the height of the cavity without visibly effecting the emission uniformity of the OLED cells. Typically, a spacer distribution having an average distance between spacer particles of about 10 - 500 μm is adequate in preventing the cap from contacting the OLED cells. In one embodiment, the density of the spacer particle distribution is about 10 - 1000 No/mm^2. Such a distribution along with the small size of the spacer particles ensures that their influence on emission uniformity is essentially invisible to the unaided human eye.

To avoid causing shorts between the electrodes, the spacer particles preferably comprise a non-conductive material. In one embodiment, the spacer particles are made of glass. Spacer particles made of other types of non-conductive materials, such as silica, polymers, or ceramic, are also useful.

In one embodiment, the spacer particles are deposited by spraying techniques. In a preferred embodiment, a dry spray technique is employed to deposit the spacer particles. Dry spray techniques are described in, for example, Birenda Bahadur (Ed), Liquid Crystals: Applications and Uses, Vol. 1 (ISBN 9810201109), which is incorporated by reference for all purposes.

Dry spray techniques typically comprise electrostatically charging the spacer particles with a first polarity (positive or negative) and the substrate with a second polarity (negative or positive). The spacer particles are blown against the substrate with dry air supplied by a dry air sprayer. Dry air sprayers, such as a DISPA-μR from Nisshin Engineering Co., can be used. Electrostatic attraction causes the spacer particles to adhere to the substrate while electrostatic repulsion between the particles prevents particle agglomeration on the substrate. A particle density of 160-180 No/mm^2 can be achieved using a dry air sprayer which generates dry air, for example, having a dew point ≤ -58°C at pressure of 2 kg/cm^2 and a current of 50 l/min for 10 s spray duration. By varying the spraying parameters, other particle densities can be achieved.

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The use of a wet spray technique to deposit the spacer particles on the substrate is also useful. Wet spray techniques are described in, for example, Birenda Bahadur (Ed), Liquid Crystals: Applications and Uses, Vol. 1 (ISBN 9810201109), which is already incorporated by reference for all purposes. Typically, the spacer particles are suspended in an alcoholic or aqueous liquids, such as ethanol, isopropanol, or a mixture comprising alcohol and water. The spacer concentration, for example, is about 0.1-0.5% by weight. Ultrasonic waves can be used to disperse the particles to prevent agglomeration. For example, the spacer particles can be irradiated with ultrasonic waves for several minutes prior to particle deposition. The prepared suspension is sprayed with air through a nozzle onto the substrate, depositing the spacer particles thereon.

Referring to Fig. 5, a second conductive layer 515 is deposited on the substrate, covering the spacer particles and other layers formed thereon. The conductive layer comprises, for example, a metallic material such as Ca, Mg, Ba, Ag or a mixture or alloy thereof. Other conductive materials, particularly those which comprises a low work function, can also be used to form the second conductive layer. In one embodiment,

the second conductive layer is patterned to form electrode strips that serve as cathode for a pixelated OLED device. Also, connections for bond pads can be formed during the patterning process. Alternatively, the conductive layer can be selectively deposited to form cathode strips and bond pad connections. Selective deposition of the conductive layer can be achieved with, for example, mask layers. The cathode strips are typically orthogonal to the anode strips. Forming cathode strips that are diagonal to the anode strips is also useful. The intersections of the top and bottom electrode strips form organic LED pixels.

Referring to Fig. 6, a cap 660 is mounted on the substrate to encapsulate the device. The cap creates a cavity 645, providing separation between it and the OLED cells. In one embodiment, a sealing frame 670 surrounding the cell region is prepared. Preparation of the sealing frame includes patterning the substrate, if necessary, to form an area for forming a sealing post 680 therein. Alternatively, the sealing frame can be formed on the cap. The height of the sealing post is sufficient to form a cavity 645 with the desired height. The use of a sealing frame is described in international patent application "Improved Encapsulation of Organic

LED Device", PCT/SG00/00133 (attorney docket number 99E5160SG), which is herein incorporated by reference for all purposes.

The cap layer 660 comprises, for example, metal or glass. Other types of caps which protect the active components from the environment, such as ceramic or metallized foil, are also useful. In yet another embodiment of the invention, the cap can be stamped or etched, depending on the material used, to form a cavity separating the cap and the OLED devices.

Various techniques can be used to mount the cap layer. In one embodiment, an adhesive is used to mount the cap layer. Adhesives such as self-hardening adhesives, UV or thermal curable adhesives, or hot melt adhesives are useful. Other techniques which employ low temperature solder materials, ultrasonic bonding, or welding techniques using inductance or laser welding are also useful.

In one embodiment of the invention, a sealing dam surrounding the device region of the substrate is provided. The sealing dam supports the cap on the substrate and provides a sealing region located at an outer face of the sealing dam. The use of a sealing dam is described in international patent application

"Sealing of Electronic Devices", PCT/SG00/00133 (attorney docket number 99E05737SG), which is herein incorporated by reference for all purposes.

During the mounting process, the spacer particles may be pressed into the layers of the OLED cells. The spacer particles provide support for the cap over the area of the OLED cells, preventing the cap from contacting the active components of the device when pressure is applied to the cap. Bond pads 650 are formed to provide electrical access to the OLED cells.

As described, the process deposits the adhesive-coated spacer particles after formation of the organic layers. The spacer particles can alternatively be deposited at other points in the process flow. For example, the spacer particles can be deposited before the formation of the first conductive layer, before the formation of the organic layers, or after the formation of the second conductive layer. In effect, the spacer particles can be deposited at any point of the process prior to mounting of the cap.

The adhesive on the spacer particles is cured at some point in the process flow after the deposition of the spacer particles. In one embodiment, the adhesive is cured after the spacer particles are deposited on the

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substrate and before the formation of the organic layers. In another embodiment, the adhesive is cured after the spacer particles are applied to the first active organic layer and before the formation of the remaining layers. In another embodiment, the adhesive is cured after the spacer particles are applied to the second organic layer and before the formation of the remaining layers. In yet another embodiment, the adhesive is cured after the spacer particles are applied to the second conductive layer and before the encapsulation of the OLED device. Spacer particles can also be useful in providing support in other types of devices that employ cavity packages. Such devices include, for example, electrical devices, mechanical devices, electromechanical devices, or microelectromechanical systems (MEMS).

While the invention has been particularly shown and described with reference to various embodiments, it will be recognized by those skilled in the art that modifications and changes may be made to the present invention without departing from the spirit and scope thereof. The scope of the invention should therefore be determined not with reference to the above description

but with reference to the appended claims along with their full scope of equivalents.